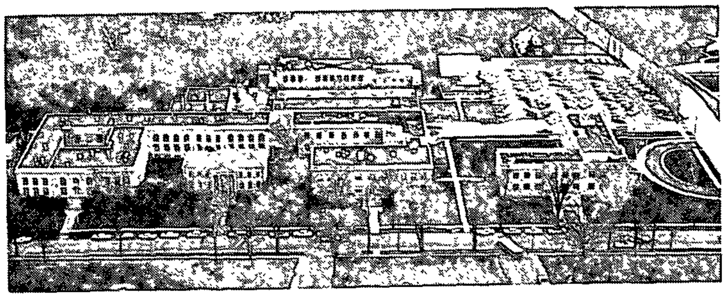

THE INSTITUTE OF PAPER CHEMISTRY, APPLETON, WISCONSIN

IPC TECHNICAL PAPER SERIES
NUMBER 273

CONTROL OF THE PAPER AND BOARD MACHINE — TODAY AND TOMORROW

GARY A. BAUM

JANUARY, 1988

Control of the Paper and Board Machine - Today and Tomorrow

Gary A. Baum

This manuscript is based on IPC research and is to be presented
at the XXIII EUCEPA Conference in Harrogate, U.K.
on May 31-June 3, 1988

CONTROL OF THE PAPER AND BOARD MACHINE - TODAY AND TOMORROW

Gary A. Baum*

ABSTRACT

Process control in the paper industry is rapidly advancing, thanks to the availability of accurate and reliable sensors, improved control schemes, and a variety of novel actuators. In particular, the CD control of basis weight, moisture, and caliper has been widely accepted and implemented during the past five years with over 1800 computer-controlled systems installed on a worldwide basis.

The next major thrust is expected to be in the control of paper and board mechanical properties. The increasing availability of novel on-line sensors that can nondestructively measure properties from which sheet strength can be inferred will eventually enable us to control the paper manufacturing process. With suitable sensors, MD control should be straightforward. Process control to give uniform mechanical properties across the machine is apt to be more challenging. It seems likely, in fact, that this objective may be at odds with current methods to obtain uniform CD basis weight and caliper profiles.

INTRODUCTION

The trend through the 1980's has been toward higher quality paper and board products. In particular, the attribute of primary concern is uniformity in the product, both in the direction of manufacture or machine direction (MD) and across the width of the web or cross-machine direction (CD). Maintaining the areal uniformity of the physical attributes of the

*James River Corporation (formerly, The Institute of Paper Chemistry).

product leads to enhanced machine productivity, with concomitant savings in energy costs, and fewer customer complaints. These benefits accrue because the control of uniformity means fewer breaks on the machine, less substandard material produced, and less broke to be repulped.

As a rule of thumb, local variations in paper or board physical properties in the MD, e.g., tensile strength, are often around $\pm$ 5%. MD variations in properties at longer times (distances) can be considerably greater than 5%, and depend on a multitude of manufacturing variables. It is with respect to these latter long term variations that MD process control is most readily applied. The variation of physical-mechanical properties in the cross-machine direction is typically $\pm$ 15% across the width of the web. Such large variation can usually be traced to manufacturing conditions on the paper machine itself and occur even though the basis weight, moisture content, and caliper profiles across the machine are all "flat". Control of this CD variation is apt to be a challenging task, which may be confounded by the automatic adjustments made in slice screw settings to control basis weight profiles.

The manufacturing variables which lead to nonuniformity in the paper or board are manifold. The chip supply can be highly variable in terms of species, moisture content, and size, which can affect the pulping and bleaching processes and hence the uniformity of the pulp coming from these operations. There can be fluctuations in the stock preparation system and in the delivery system to the headbox. Too often, the papermaker may use the refiners as a "cure-all" for some problem that originates elsewhere. The broke handling system may seriously affect final sheet properties if the amount of broke utilized fluctuates greatly. The chemistry of the stock system can vary considerably, for a variety of reasons, with significant impact on sheet properties, e.g., (1).

Many of the above parameters can be monitored with some success, as discussed later, and this is a first requirement in controlling them. Most of them impact the long time variation of the MD properties of the paper or board. The paper machine operating variables, however, must be thought of in a different light, because they impact both MD and CD physical properties. It is on the paper machine itself that we create the orthotropic character (directionality) of the product. Some of the machine operating variables can be monitored in the MD, but only a few in the CD.

The machine variables of interest will depend on the nature of the manufacturing equipment and its configuration but would include conditions at the slice (extent of flocculation, jet-to-wire speed differentials, transverse (CD) stock flows); drainage; wet pressing pressure, time, and temperature; draws or wet stretching of the wet web; and conditions in the dryer section (e.g., extent of CD restraint during drying).

CONTROL IN THE MACHINE DIRECTION

Control of the manufacturing process to minimize variations in MD sheet properties is primarily one of controlling all input streams and processes, especially yield, refining (freeness), consistency, overall basis weight, and those machine parameters referred to above. Ideally the process management would be carried out in an integrated fashion such that when combined with product quality inputs, one would have both process and quality control.

Although local control of some unit processes has been achieved and advances are being made every day, complete integrated control is not yet possible, primarily due to a lack of suitable sensors to measure the appropriate attributes. For example, while it is possible to continuously monitor the mass and moisture content of the chip supply stream and adjust pulping chemicals accordingly, it is not possible to monitor lignin content in the digester. Although there have been some recent advances in "lignin" sensors (2), there is still a need for the additional development of such sensors.

The measurement of consistency is a basic paper mill requirement. Interestingly, although there are numerous ways to "measure" consistency, based on different physical phenomena, no one sensor type seems to be adequate in all situations (3). All consistency "transmitters" are apparently subject to interferences from changes in other variables besides consistency (e.g., flowrate, freeness, etc.) (4,5).

Pulp "freeness" or "drainage" are terms used to describe how well the pulp will "perform" on the paper machine wire and/or the quality (often strength) of the final sheet. They are measures of pulp quality, defined in terms of laboratory measurements, but cannot be measured continuously on the paper machine. There are several "on-line" sensors which make repeated measurements of "drainage" using a batch type process on stock taken from the main pulp stream, e.g., (6). Such measurements are useful but a continuous method of measuring pulp quality would be desirable, especially for control of the refining process. One measure of pulp quality might be the flexibility of the wet fibers, since altering this is one of the major effects of refining on fibers. Continuously measuring the flexibility of fibers in a flowing slurry, however, appears to be a monumental task (7).

In the paper mill, the general trend is to minimize changes in the paper machine variables. The latter ideally are adjusted to provide the optimum desirable sheet properties. Unfortunately, the variation in pulp quality usually precludes such an ideal situation for long. Some variables, e.g., wet pressing pressure, may not readily lend themselves to continuous adjustment in response to a change in sheet properties. Crowned press rolls, for example, are designed to operate in a particular pressure regime. On the other hand, changes in refining level, jet-to-wire speed differentials (rush-drag), or the tightness of the draws can, and are, used to respond to unexpected aberrations in sheet physical properties. In general, however, these are not used in a closed loop scheme to control web properties. There may be local control of the refiners, based on power input or some other indirect measurement. While there is quite a bit of work going on in this area, automatic control of the variables on the paper machine seems to be some way off.

Instead of monitoring machine variables, the need is to monitor the properties of the web directly, and use these values as inputs to control the machine variables. It is possible to measure a number of physical attributes of the paper web during its manufacture (8). Sensors to measure basis weight (BW) and moisture content (MC), of course, are highly developed and their mean values are routinely used for MD control. Also advanced, but less common, are caliper or thickness sensors used in a feed back fashion to control the calendering process (9), and on-line color measurements to control the addition of dyes at the wet end. Other sensors are available to measure formation, surface roughness, ash content, and optical properties such as gloss, brightness, or opacity. These latter sensors are primarily used for monitoring product quality, however, rather than as inputs for automatic control of the process in the machine direction. While most of them are quite sophisticated and reliable, they are not necessarily widely used. Wahren has reviewed many of the recent developments with respect to on-line property control (10).

CONTROL IN THE CROSS-MACHINE DIRECTION

There have been significant advances in the past two decades in monitoring basis weight and moisture content in the cross-machine direction. Such CD profiles provide information in real time as to the location of basis weight excursions or moisture streaks, and thus offer the opportunity to take appropriate corrective action. Despite the availability of suitable sensors for almost 20 years, it has only been in the last five years or so that automatic control of basis weight and moisture content in the cross-machine direction has begun to grow. There are two apparent reasons for this. The first has been the availability of reliable actuators to control CD variations in BW or MC. The second has to do with the development of fast microcomputers, the networking of such computers, and the development of suitable algorithms and software.

The first CD control of BW was on a small fine paper machine in 1970 (11). Through 1986, over 1800 CD actuators have been installed worldwide in closed loop control of BW, MC, or caliper, almost doubling over a two-year period (12). This trend will increase as the benefits of such systems are more widely recognized and as actuators and computing performance improve.

While the dry weight profile is influenced by many factors such as headbox disturbances, uneven or damaged dewatering elements, or slice/apron lip imperfections, the slice profile is the principal control factor regardless of the source of the problem (13). Complications occur because of the complex relationship between local slice opening and basis weight at the dry end (14), and because the scanning sensor is confounded by the MD displacement of the web during a CD scan. This latter difficulty is handled by using an exponential weighting factor to filter the MD component (15). The former point has led to the development of algorithms which adjust adjacent slice screws in groups, rather than singly, to account for the interactions that occur between adjacent slice openings. Three types of slice lip actuators are available: individually controlled electric motors; thermal expanding rods; and thermal hydraulic rods. The type of actuator chosen for a given situation will primarily depend on the type of application, the required response time, and cost.

The MD translation of the web during a CD scan also causes complications in the case of moisture or caliper control. Most moisture sensors used today are based on the absorption of infrared or microwave radiation by the water present in the web. Usage depends on the furnish, basis weight, and moisture content range to be monitored. Such sensors are sophisticated and can "look" at a small area of the web, to give an accurate indication of moisture content (if they are calibrated properly). The local moisture content of a small area of the sheet, however, may vary widely from that of its neighbors. Such small scale variations usually are not of interest and must be filtered out. This filtering is in addition to that required by the MD translation of the web at a given scanning sensor speed.

Control of CD moisture variations typically amounts to either adding water where MC is too low or removing water locally where it is too high. An obvious problem with either approach is to control the width of application of the steam, water, or localized drying (10, 16). This apparently is done satisfactorily because there are numerous "success" stories in the literature, e.g., (17). Moisture profiles are influenced by many factors and it is good practice to try and locate and eliminate the source of the problem, if possible, rather than have the CD moisture actuator try to compensate for the problem. Such problems may be related to adjustment of press nips, press felt cleanliness or age, or to nonuniform heating of the dryer cans. These generally must be corrected by manually making process changes.

Caliper profile control is a scenario similar to those mentioned for basis weight and moisture content. While the principles behind the sensors to measure caliper on-line are different than those for BW or MC, filtering schemes to process the information gathered are still required, and actuators to control local caliper may not have a resolution to match the sensor resolution. However, there are again numerous descriptions of successful systems, e.g., (18).

In summary, the importance and advantages of maintaining "flat" CD profiles of basis weight, moisture content, and caliper are understood and appreciated by the industry. The problems associated with CD profile control are also reasonably well understood (19, 20). The state of the technology today is quite sophisticated and the results obtained are satisfactory. It is very probable that such closed loop systems for CD profile control will be significantly improved in the next decade. This would happen naturally as improvements are made in control algorithms, actuators, process equipment, and in computer hardware. I believe, however, that the improvements will be driven faster by the sensor developments that are underway and described in the following section, and by our rapidly expanding base of understanding of how papermaking variables interact and influence the development of sheet properties.

TOTAL CONTROL OF THE PAPERMAKING PROCESS

The above discussions have been concerned with what is done today in terms of control of the paper or board machine. While the subject treatment has not been comprehensive or treated in depth, it should convey the sense that automatic control is an important and rapidly growing area. But it should also be clear from the above discussion that total control of the paper machine is not yet possible. It is not yet possible because we lack appropriate sensors to monitor all the variables of interest and we lack the understanding of how these paper machine variables interact to produce sheet properties. Given these, it seems probable that appropriate actuators could be developed in time. The necessary computing requirements probably already exist. It would appear that we are on the verge of total paper machine control if we can develop the necessary sensors and can collect the information required to establish relationships between all of the variables (and there are a lot of them) in the papermaking process and their influence on sheet properties. This will contribute significantly to the goal of mill-wide control.

Instrumentation and automatic control are two major aspects of the rapidly growing field of information technology. In fact they have been cited as enabling technologies which are essential to the effective application of information technology in many areas (21). Sensors may be thought of as information machines feeding information systems, which in turn are related to distinct and specific technology. The development of the algorithms that are to be implemented requires a thorough understanding of the physical behavior of the processes and hardware involved and the ability to model them.

Let me expand on a key point in the last paragraph. We need to understand how papermaking variables affect sheet properties. We need to know how the variables collectively interact to affect sheet properties, not just one at a time. For example, increasing refining, wet pressing pressure, or draws will all increase MD tensile strength, but they do so for different reasons, and have different effects on other physical properties, such as MD or ZD (thickness direction) tensile strength. If we were trying to control the process using an on-line measurement of MD tensile, we would not know which of the three papermaking variables mentioned to work with. Of course, the problem is even more complicated because, by definition, we cannot measure strength properties on the paper machine since they are destructive tests.

Since virtually all paper and board grades have some mechanical property specification, such as tensile strength, tearing strength, stretch, etc., and since these cannot be measured on the moving paper web, it is necessary to find a collection of parameters that can be measured on-machine. The elastic stiffnesses of paper, which relate the resultant stresses to the applied strains, is one such set of parameters (22) that can be measured in the laboratory. Laboratory instruments have been developed at The Institute of Paper Chemistry which are capable of rapidly measuring seven of the nine elastic stiffnesses required to describe machine-made paper (23). Furthermore, the IPC work has shown that the elastic stiffnesses each respond in different ways to changes in paper machine variables (24). Thus, if all of these elastic stiffnesses could be measured on a moving paper web, it should be possible in many instances to relate the changes observed in (the collection of) them to a change in a specific machine variable. The ability to do this, to relate changes in paper properties to one specific process variable out of the multitude of them, is just what is needed to begin to learn how to control the paper or board machine.

As an added benefit, some of the elastic stiffnesses are related to certain physical properties of the sheet already used to assess product performance. For example, MD, CD, and ZD tensile strengths are each related to a single, different, elastic stiffness, and CD compressive strength is related to a product of two elastic stiffnesses (24). Thus if these stiffnesses could be measured on moving webs, it would be possible in many instances to predict product quality during the manufacturing process, as well as offering means for automatic control of the process to achieve target values.

As a part of their work in this area, IPC researchers developed several instruments which were capable of measuring two of the elastic stiffnesses on moving webs (25). The instruments were tested in mill trials on several grades, and the technology was subsequently licensed to a number of instrument manufacturers. Several of these manufacturers have recently discussed successful results using their sensors (26, 27, 28).

WHAT IS NEEDED

What is needed for control of the process? Prior to the headbox, the earlier discussions suggest some specific sensors are required. In particular, sensors to continuously monitor lignin content and pulp "quality" are needed. Pulp quality needs to be defined. Better consistency transmitters need to be developed. The chemistry at the wet end of the paper machine needs to be monitored and controlled to prevent wide swings that cause upsets further along in the papermaking process or degrade sheet characteristics. The appropriate chemistry attributes to be monitored need to be defined.

What is needed for control of the paper or board machine itself? First, on-machine sensing of properties that are related to machine operating variables in known and predictable ways. The elastic stiffnesses may be such a set of properties. Second, on-machine sensing of properties that can be related to end-use or converting requirements. Again, the elastic stiffnesses may be such a set of properties. Third, development of techniques and actuators to control machine operations. Last, integration of the various control schemes (MD and CD) and with other mill process streams for automatic control of the manufacturing process, and ultimately mill-wide control.

Today we are in the early stages of sensor development for measuring elastic stiffnesses on the paper machine. At present we know how to measure two or three elastic stiffnesses (out of nine) on moving webs. I previously suggested that at least three elastic stiffnesses will be required to initiate rudimentary control of the paper machine (29). These include two elastic stiffnesses in the plane of the paper and one elastic stiffness in the ZD of the paper. The three particular elastic stiffnesses of interest probably are not essential to this discussion. Suffice it to say that they will permit a separation of the effects of several machine variables on sheet properties. For example, it should be possible to separate the effects of refining, jet-to-wire speed ratio (rush-drag), and draws on sheet properties. This means that by monitoring how the three stiffnesses change relative to each other, it will be possible to take a corrective action on one or more of these three machine variables. Of course it will be necessary to develop suitable actuators or process modifications to do this. Work is underway now at IPC to develop a single sensor capable of measuring the three elastic stiffnesses of interest.

As mentioned earlier, we appear to be on the verge of total closed loop control of the paper making process. Once we learn how to control the paper machine itself, tying all the various processes together should soon follow. It would be reasonable to expect such complete systems, although perhaps primitive, by the early 1990's.

REFERENCES

1. Scott, W. E., "Fines management and control in wet-end chemistry", Tappi J. 69(11):30(1986).

2. Gorfelt, P., S. Skogsagarna AB, and M. Bruk, "On-line kappa number sensor for oxygen bleach plant control", Proc. Control Systems '86, Stockholm, May 26-30, 1986.

3. Consistency meter survey, American Paper Institute Instrumentation Program Report No. 63, November 18, 1981.

4. Hardacker, K. W., "A study of in-line consistency transmitters", American Paper Institute Instrumenation Program Report No. 65, March 29, 1983.

5. Hardacker, K. W., "A study of in-line consistency transmitters", American Paper Institute Instrumentation Program Report No. 67, February 28, 1986.

6. Sipprell, R. D., "Effective use of on-line freeness testing equipment", Proc. 1985 TAPPI Pulping Conference, November 3-7, 1985, pp. 365-366.

7. Habeger, C. C., and G. A. Baum, "Ultrasonic characterization of fiber suspensions", In the Role of Fundamental Research in Papermaking, Transactions of the Cambridge Symposium: September 1981. Mechanical Engineering Publications Ltd., London, 1983.

8. Walbaum, H. H., and K. Lisnyansky, "Review of process control instruments for measuring paper quality variables", Paper Trade J., pp. 37-42, (July 15 & 30, 1983, and pp. 34-40, August 15, 1983.

9. Crotogino, R., and S. Gendron, "Control systems for calenders and supercalenders - Potential and limitations", Proc. Control Systems '86, Stockholm, May 26-30, 1986.

10. Wahren, D., "Recent highlights in paper technology", Tappi J. 69(3), 36 (1986).

11. Beecher, A. E. and R. A. Bareiss, "Theory and Practice of Automatic Control of Basis Weight Profiles", Tappi 53(5):847(1970). Stockholm, May 26-30, 1986.

12. Smith, K. E., "Cross-direction control sales have doubled in the past two years", Pulp & Paper 61(3):48(1987).

13. Karlsson, H., I. Lundqvist, and T. Ostman, "Principles and Potentials of CD-Basis Weight Control", in Proc. EUCEPA Symposium Control Systems in the Pulp and Paper Industry, Stockholm, May 11-14, 1982.

14. Karlsson, H., L. Haglund, and A. Hansson, "Optimal cross-direction basis weight and moisture profile control on paper machines", Pulp & Paper Canada 86(8):43 (1985).

15. Higham, J., "The changing face of paper machine controls - cross direction and beyond", Proc. TAPPI 1985 Process Control Symposium, Boston, March 31-April 3, 1985.

16. Brewster, D. B., "Interactions in cross-direction controls", Pima, 68(12):28 (December, 1986).

17. Lindstrom, R., "Total profile control: One company's experience", Pima, 61(11):28 (November, 1985)

18. Boissevain, M., "Bowater Southern flattens caliper profile with Caltrol calender actuator," Paper Trade J. 170(1):45(Jan., 1986).

19. Holik, M., "Improved paper quality by optimum CD profile control", Proc. Control Systems '86, Stockholm, May 26-30, 1986.

20. Mohr, W. C., "Effects of ergonomics, electronics, and machine design on CD control", Proc. Control Systems '86, Stockholm, May 26-30, 1986.

21. Finkelstein, L., "Instrumentation, control, and information technology", J. Physics E.: Sci. Inst. 19: 246 (1986).

22. Habeger, C. C., R. W. Mann, and G. A. Baum, "Ultrasonic plate waves in paper", Ultrasonics 17:57(1979).

23. Van Zummeren, M. L., D. J. Young, C. C. Habeger, G. A. Baum, and R. Treleven, "Automatic determination of ultrasound velocities in planar materials", Ultrasonics 25:288(1987).

24. Baum, G. A., "Elastic properties, product quality, and process control", Appita 40(4):288(1987).

25. Habeger, C. C., and G. A. Baum, "On-line measurement of paper mechanical properties", Tappi J. 63(7):63(1980) and Tappi J. 69(6): 106(1986).

26. Vahey, D., "Ultrasonic based strength sensor for on-line measurements", Tappi J. 70(3):79(1987).

27. Vahey, D. W., "Correlation of the on-line ultrasonic velocity measurement with end-use strength properties", presented at 1987 TAPPI Managing Quality Seminar, October 11-14, Elizabeth, NJ.

28. Chase, L., "On-line Measurement and Control: Requirements, Results and Economic Improvements in Papermaking", presented at 1987 Miami Symposium, Miami University, June 1-4, Oxford, OH.

29. Baum, G. A., and C. C. Habeger, Jr., "On-line estimates of strength", Proc. Control Systems '86, Stockholm, May 26-30, 1986.